

Earth Orientation Effects on Mobile VLBI Baselines

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Improvements in data quality for the Mobile VLBI systems have placed higher accuracy requirements on earth orientation calibrations. Errors in these calibrations may give rise to systematic effects in the nonlength components of the baselines. In this work, various sources of earth orientation data were investigated for calibration of Mobile VLBI baselines. Significant differences in quality were found between the several available sources of UT1-UTC. The JPL Kalman-filtered space-technology data were found to be at least as good as any other and adequate to the needs of current Mobile VLBI systems and observing plans. For polar motion, the values from all services suffice. In addition, the effect of earth-orientation errors on the accuracy of differenced baselines (i.e., baselines between Mobile VLBI sites which were not simultaneously occupied) was investigated. This effect was found to be negligible for the current mobile systems and observing plan.

I. Introduction

The Mobile VLBI systems developed at JPL¹ have been producing high quality data since the beginning of 1980 (Ref. 1). Hardware upgrades made during this interval include conversion to wideband receivers, the Mark III data acquisition system, and dual (S- and X-band) frequency capability. These improvements have resulted in single measurements of baseline length with formal errors of less than 1 cm and repeatability of 1 to 2 cm.

To achieve similar accuracy in the measurement of non-length components requires an additional calibration. This is due to the fact that the VLBI technique provides a very accurate measurement of the baseline within the reference frame of the quasi-stellar radio sources (Ref. 2). However, measurement

of the various components of these baselines in an earth-fixed frame requires very precise knowledge of the orientation of the earth in space.

II. Earth Orientation Calibration of Baselines

By using a worldwide network of VLBI stations located in regions where local earth motion is not common, it would be possible to estimate the baselines and the earth orientation parameters from the same data set (Ref. 3). However, the Mobile VLBI baselines do not satisfy either of these criteria since they are measured between stations on the western U.S. coast. Furthermore, solving for earth orientation in an absolute sense requires placing some kind of constraint or model on the motion of the baselines. This risks the contamination of earth motions by imposing a possibly incorrect model. Thus, it is necessary to use an external source for the values of UT1-UTC and polar motion (UTPM).

¹ Allen, S. L., et al., "Current Mobile VLBI Data Base," Submitted to the NASA Crustal Dynamics Data Information System, Goddard Space Flight Center, Greenbelt, Maryland, May 1984.

A. Services Providing Earth Orientation Data

In order to calibrate the Mobile VLBI data it is desirable to have a self-consistent, high-precision UTPM data set which spans the entire history of the mobile experiments. The highest precision techniques for measuring UTPM are lunar laser ranging (LLR) and VLBI. Such measurements are presently carried out by several independent groups. Unfortunately, neither of these techniques has a complete data span overlapping with Mobile VLBI. It is necessary to use UTPM data from a service which combines the raw data from several techniques. Four services provide such combined data: the U.S. Naval Observatory, the International Time Bureau (BIH), Dr. Robert W. King (MIT Combination Solution; Ref. 4), and T. M. Eubanks (JPL Kalman-filtered space-technology data; Ref. 5). In the present work the latter three types have been applied to the Mobile VLBI data in order to evaluate their usefulness in removing systematic trends.

Since a combination solution for UT and PM is typically only as accurate as its input data, it is instructive to consider the expected accuracies of several different services of UT and PM. These figures are given in Table 1.

The values for the first three services are derived from past performance (Refs. 4, 5). The values of the last service are predicted from a covariance analysis (Ref. 6). These represent the accuracy of UTPM measurements which can be expected within the next two years.

The frequency of observation of the earth orientation services is also of importance to the calculation of differenced baselines. Astrometric UT and polar motion are derived from many daily observations of lower precision than LLR or VLBI. Although the frequency of these observations is greater than that of LLR or VLBI, the smoothing which is required removes much of the high-frequency signal. However, the relatively quick data reduction of the astrometric data makes them available for services such as the BIH Circular D. VLBI makes high-precision observations of UT and PM, but these are generally obtained at intervals of one week. LLR comes closest to providing daily, high-precision values of earth orientation, but even so, LLR cannot make observations for a week around new moon. To recover a value of UT and PM at the epoch of a Mobile VLBI experiment, it is necessary to interpolate or filter.

For polar motion the interpolation can be done simply and accurately because there are no large amplitude components with frequencies less than 2 weeks. This is not the case for UT1-UTC. Recent investigations indicate that even if UT were perfectly measured at 5-day intervals, the one-sigma uncertainty in interpolating midway between the measured points would be at least 0.5 ms (Ref. 7). As discussed in Sec-

tion III, this has implications for the computation of differenced baselines. It requires appropriate deployment of mobile units and the use of base stations to minimize differencing errors.

B. Results of Earth-Orientation Calibrations

The most often measured Mobile VLBI baselines are those between JPL in Pasadena, Calif., Owens Valley Radio Observatory (OVRO), near Lone Pine, Calif., and DSS-13, at the NASA Goldstone complex (the JOG triangle). The baselines vary in length from 171 km to 336 km. There are also many measurements of the Owens Valley to Ft. Davis, Texas (HRAS) baseline. This baseline is 1508-km long; thus, its sensitivity to rotations is a factor of 5 greater than any JOG baseline.

Deficiencies in UTPM calibration show up as scatter in the nonlength components between one experiment solution and another. On these relatively short, regional baselines, the vertical direction is nearly coincident for each station. This allows nonlength error sources to be relatively easily separated into two perpendicular components: transverse and vertical.

The scatter of points in the vertical direction is caused by unmodeled day-to-day changes in the tropospheric path delay. The uncertainties in the troposphere calibration commonly cause 10-cm variations in the baseline vertical component. This effect is larger than the deficiencies in UTPM, and it masks any rotations along this direction. Fortunately, the transverse baseline components are not affected by any large systematic errors except UTPM; they provide a sensitive probe of UTPM.

The Mobile VLBI data for the JOG triangle are presented with three different calibrations in Figs. 1, 2 and 3. These are plots of the transverse component of the baseline vs experiment date. For each plot, the RMS deviation from a fitted line and the chi-squared per degree of freedom are given.

With the BIH Circular D values of UT1-UTC, the points which are closely spaced in time cluster quite well. These closely spaced points were obtained during the same mobile field exercise or "burst." However, from one cluster to another, shifts in the transverse component are evident. These shifts are especially noticeable on the OVRO/DSS-13 baseline. The other UT1-UTC series greatly reduces the shift from one mobile burst to another.

Figure 4 contains a similar comparison plot for the OVRO/HRAS baseline. The effect of deficiencies in UTPM is much greater on this baseline. The first two points in this baseline are known to contain systematic errors unrelated to UTPM. (These points are labelled H and I, and they are unimportant to this discussion.) Again, on this baseline the transverse

scatter is reduced by using the MIT and JPL values of UT1-UTC.

Figure 5 presents the OVRO/HRAS baseline in another form. The ellipses are the projection onto the transverse-vertical plane of the 3-D error ellipsoids obtained from each solution. Since this plane is perpendicular to the baseline, rotations of the baseline naturally show up as deflections on the plot. Of course, vertical deflections may also be caused by troposphere calibration errors. The inset vectors in each plot show the magnitude and direction of typical displacements caused by variations in UTPM. Point C in the JPL plot (Fig. 5[b]) has a very large uncertainty in UT1-UTC due to gaps in the Kalman filter's input data. The BIH Circular D calibration is not shown because its scatter exceeds the boundaries of this plot.

From Figs. 1, 2, and 3 it is clear that the MIT and JPL UT1-UTC values give less scatter than the BIH Circular D. The two series produce results which are comparable in transverse scatter. The JPL Kalman-filtered space data produce a slightly narrower vertical column of ellipses in Fig. 5(b); however, further data will be required to draw definite conclusions about the relative merits of the JPL and MIT combination solutions.

A similar investigation was carried out on these data using various sources of polar motion. In no case was the result of one polar motion calibration significantly better than any other. More data, preferably with longer baselines, will be required before Mobile VLBI data can be used to make a significant evaluation of polar motion data services. For present purposes, BIH Circular D suffices for the calibration of polar motion.

III. Differenced Baselines

A differenced baseline is defined as a baseline between two mobile VLBI sites which were not occupied simultaneously. Unlike the simultaneously measured "direct" baselines, the length of a differenced baseline can be affected by deficiencies in UTPM calibration. Doubt regarding the size of this error and the model necessary to best remove the error has prevented the report of any differenced baselines before this time. The capability of producing differenced baselines would greatly increase the data yield of Mobile VLBI experiments, and it would permit a rethinking of the deployment strategy for the Mobile VLBI units.

A. Error Sources

Typically, a differenced baseline would be formed from two separate solutions involving VLBI networks operated on

different days. The mobile sites would not be the same for the two experiments, but at least one of the base stations would be identical. Differenced baselines would be trivial to compute given two assumptions: first, that no crustal motion occurs during the interval between occupations of the different sites; second, the earth orientation is known exactly for the occupations. The calculation would simply involve taking the difference of the vectors to each of the sites (hence the term "differenced baseline") and adding the covariance matrices to compute the errors.

The possibility of actual motion of the sites between occupations degrades the accuracy of a differenced baseline. Hence, we restrict calculation of differenced baselines to occupations in the same burst, with the maximum intervals between occupations of the endpoints of a differenced baseline being about 3 weeks. Even a baseline moving 6 cm per year would only move 5 mm in 3 weeks, and most measured baselines appear to be changing by less than 2 cm per year. Barring earthquakes, the uncertainty in the troposphere and ocean-loading corrections is larger than this motion; hence, earth motion will be ignored here. Errors in earth orientation for the two days would cause a misalignment of the two networks. More precisely, the solution on each day would be expressed in a different, slightly rotated coordinate system. This would cause a systematic error in a differenced baseline produced from these solutions.

B. Computation and Error Modeling

The geometry involved in the computation of a differenced baseline is depicted in Fig. 6. Figure 6(a) shows a scenario with one base station and a mobile station which occupies two sites on two different days. The uncertainty in the source of earth orientation on each day is represented as an error arc perpendicular to the baseline from base station to mobile site. The differenced baseline receives error contribution from each mobile site. Figure 6(b) depicts the geometry of a three-base-station experiment. All three base stations are active on both observing days, and the mobile moves from one site to another. In this case the base-station network can be used to solve for the difference in earth-orientation parameters between the two days, using the values obtained from an earth orientation service as *a priori* information. Only the baseline from each mobile site to the nearest base station is shown, though all are measured. This is done in order to emphasize that when earth orientation is not known exactly, the shortest baseline to the mobile units serves as the tightest constraint on their positions.

The results of a differenced baseline calculation should be independent of the choice of reference station in the solution. Figure 6(c) shows another three-base-station scenario where

both mobile sites are closest to the same base station. If the correlations between all stations were not included, then choosing different reference stations would produce different error estimates for the differenced baseline. This would be physically unreasonable. JPL's multiparameter least-squares fitting program MASTERFIT (Ref. 8) does handle all correlations properly; differenced baselines produced by MASTERFIT are independent of the choice of reference station.

The results of a differenced baseline calculation should also be independent of arbitrary choices used to define UT and PM. Consider the effect in Fig. 6(a) if day 1 of the burst were chosen to have UT and PM fixed with zero error. Since the baseline on day 2 is much longer than the baseline on day 1, its uncertainty is much larger. Although the post-fit error in the length of the differenced baseline is the same with either day chosen as reference, the error in the transverse component is much larger if day 1 is fixed. This is also a nonphysical result caused by the assumption of perfect knowledge of the coordinate system on a particular day.

The correct strategy for producing post-fit errors which are not dependent on arbitrary choices of a reference day is as follows. Assume that earth-orientation services provide values which are correct but lacking in the high-frequency components (i.e., periods of less than ~ 5 days). Thus, the data from consecutive experiments with common base stations can still be quite useful for tracking the day-to-day differences which were not resolved by the UTPM service. For each experiment set UT and PM to the values from the service, and assign *a priori* constraints equal to the errors quoted by the service. If possible, the day-to-day correlations of the UTPM values should also be used. This will force the post-fit values of earth orientation to agree in the mean with the service supplying UT and PM, but it will also allow the VLBI data to adjust the differences between one day and the next in order to remove misalignment of the networks. This use of both *a priori* and VLBI data correctly utilizes the available information, and it is simple to implement in MASTERFIT.

C. Estimated Errors

The errors which may be expected on differenced baselines are described below. These errors were calculated using the assumption that an individual baseline is measured with an uncertainty of 2 cm in its length and transverse components and 9 cm in the vertical component. The values of the earth-orientation services' uncertainties were set *a priori* to the values given in Table 1 and constrained using the VLBI network to determine the post-fit uncertainty in UT and PM. These uncertainties were propagated to the mobile stations along the shortest baseline from mobile to base station. Although this is not a full covariance analysis, it serves to set

upper limits on the errors which will be encountered when actually reducing data.

The tables and figures give the estimated errors in the "rational" coordinate system (in which the principle axes are along the baseline length, vertical, and transverse directions) for various arrangements of base stations and mobile sites. Note that when there are three or more base stations, the VLBI data alone are sufficient in principle to determine earth orientation. However, due to the large vertical uncertainties on the baselines caused by troposphere, the earth-orientation value obtained from a service always serves as the tighter constraint in the vertical direction.

The additional error accrued quadratically to a differenced baseline due to UT and PM uncertainties is given in Tables 2 through 5. Table 2 details the effects when four base stations are operated on both days of the experiment, including the antenna in Ft. Davis, Texas (HRAS). This network allows for very precise determination of earth-orientation differences using the Mobile VLBI data. The additional errors are tabulated for several baselines in California using *a priori* errors for UT and PM from the various services described above. These errors are expressed in the rational coordinate system of components: the length, the component transverse to length, the vertical component, and the root sum of squares of all three components.

Table 3 gives the same figures when calculated without the presence of HRAS, and Tables 4 and 5 reduce the number of base stations to 2 and 1, respectively. It is clear that the presence of more and longer base-station baselines reduces the amount of error due to uncertainty in earth orientation. Plots of these errors are given in Figs. 7, 8, and 9 for a cross section of the data in the tables.

The interpretation of these tables and plots must be made with the understanding that this is the extra error due only to UT and PM uncertainty. These must be combined with the other errors inherent in the VLBI system to produce the full error. Figures 9 and 10 illustrate this point. Figure 9 shows the worst tabulated case of differenced baseline error. There is only one reference station (OVRO). Figure 10 shows the very same errors with a VLBI system noise of 2 cm in the length and transverse added. Only in the case of the astrometric UT and PM is there a significant degradation of accuracy for the differenced baseline.

Thus, differenced baselines within California do not suffer significant degradation due to uncertainties in earth orientation. However, the above analysis should not be taken to mean that only one base station is sufficient for the calculation of differenced baselines. It is very important that there be a base

station relatively near the mobile locations; e.g., a base station in Massachusetts with mobile units in California gives very large errors for a differenced baseline.

When more than one mobile unit is available and base stations are nearby, each mobile unit can move between each experiment. In the simple case of one base station and two mobile stations, differencing increases the number of baselines produced per burst of n site occupations from $3n$ to $(n+1)(n+2)/2$. When base stations are far away, two mobile units can work together to serve as base stations for each other. In this case each mobile unit remains at each site for 2 experiments while the other moves. Each extra base station serves to decrease the VLBI system noise by providing more data. More importantly, redundancy in the base stations helps prevent errors such as those which can be seen in Figs. 11 and 12.

The February 1983 burst provided an opportunity to calculate differenced baselines using real data. Experiments H83A and H83B shared the base stations OVRO, JPL, and Vandenberg. MV3 occupied Pearblossom and Pinyon Flat on the two days, respectively. These experiments allowed for a solution of a differenced baseline using MASTERFIT. Figure 11 shows the results of the solution when all three base stations were used and when only pairs of the base stations were used. All of the solutions agree, although the solution with all three base stations has slightly smaller errors. Figure 12 shows the same experiment when only one base station is used as a reference. The JPL-and-OVRO-only solutions

still agree well with the full network solution; however, the Vandenberg-only solution differs by several sigma.

IV. Conclusion

For Mobile VLBI baselines with lengths less than 1000 km, it now is possible to remove all significant errors caused by uncertainties in earth orientation. This can be achieved using either the JPL or MIT combination solutions. The continued efforts to develop VLBI and laser systems for UTPM measurement should insure that this high accuracy is improved in the future. Thus, for regional work, earth orientation will no longer pose a problem, at least until other system errors are reduced below a level of 1 cm.

The occasionally measured longer baselines from the Mobile VLBI systems will continue to serve as indicators by which UTPM data sets can be evaluated. Calibration of the long baseline data will provide information on the systematic errors remaining in the UTPM combinations.

The computation of differenced baselines is a simple and natural way to take full advantage of the data produced by the Mobile VLBI project. Their inclusion approximately doubles the number of baselines produced under the current deployment plan. The additional error encountered on these differenced baselines will usually be small in comparison to the other errors in the VLBI error budget. The base-station baselines are also enhanced by the inclusion of more data into a single coherent solution.

References

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Table 1. Typical errors for various sources of UT and PM

Earth Orientation Component	Source			
	Astrometric	Lunar Laser Ranging (LLR)	VLBI	3 Station "Super" LLR (Predicted)
σ UT1, ms	1.25	0.4	0.3	0.07
σ PMX, marcsec	7	7	3	2.0
σ PMY, marcsec	7	5	7	1.5

Table 2. Differenced baseline error: Additional error (in cm) for differenced baselines due to UT and PM OVRO, Mojave, Vandenberg, and HRAS as fixed base stations

Baseline	Source of Earth Orientation			
	Astrometric	LLR	VLBI	"Super" LLR
Monument Peak - Quincy	σ L = 0.12	σ L = 0.10	σ L = 0.11	σ L = 0.06
	σ T = 0.41	σ T = 0.37	σ T = 0.37	σ T = 0.25
	σ V = 1.38	σ V = 1.06	σ V = 1.22	σ V = 0.33
	RSS = 1.45	RSS = 1.13	RSS = 1.28	RSS = 0.42
Pt. Reyes - Yuma	σ L = 0.16	σ L = 0.15	σ L = 0.16	σ L = 0.10
	σ T = 0.46	σ T = 0.41	σ T = 0.42	σ T = 0.29
	σ V = 1.59	σ V = 1.21	σ V = 1.22	σ V = 0.35
	RSS = 1.66	RSS = 1.29	RSS = 1.30	RSS = 0.46
Sta. Paula - Pearblossom	σ L = 0.08	σ L = 0.07	σ L = 0.07	σ L = 0.05
	σ T = 0.14	σ T = 0.13	σ T = 0.14	σ T = 0.09
	σ V = 0.63	σ V = 0.48	σ V = 0.37	σ V = 0.13
	RSS = 0.65	RSS = 0.50	RSS = 0.40	RSS = 0.16

Table 3. Differenced baseline error: Additional error (in cm) for differenced baselines due to UT and PM OVRO, Mojave, Vandenberg used as fixed base stations

Baseline	Source of Earth Orientation			
	Astrometric	LLR	VLBI	"Super" LLR
Monument Peak - Quincy	$\sigma L = 0.30$	$\sigma L = 0.24$	$\sigma L = 0.21$	$\sigma L = 0.08$
	$\sigma T = 1.45$	$\sigma T = 1.08$	$\sigma T = 0.84$	$\sigma T = 0.36$
	$\sigma V = 1.93$	$\sigma V = 1.20$	$\sigma V = 1.44$	$\sigma V = 0.33$
	RSS = 2.43	RSS = 1.63	RSS = 1.68	RSS = 0.50
Pt. Reyes - Yuma	$\sigma L = 0.49$	$\sigma L = 0.41$	$\sigma L = 0.33$	$\sigma L = 0.14$
	$\sigma T = 1.62$	$\sigma T = 1.24$	$\sigma T = 0.96$	$\sigma T = 0.41$
	$\sigma V = 2.90$	$\sigma V = 1.51$	$\sigma V = 1.49$	$\sigma V = 0.36$
	RSS = 3.36	RSS = 2.00	RSS = 1.80	RSS = 0.57
Sta. Paula - Pearblossom	$\sigma L = 0.27$	$\sigma L = 0.21$	$\sigma L = 0.16$	$\sigma L = 0.07$
	$\sigma T = 0.51$	$\sigma T = 0.40$	$\sigma T = 0.31$	$\sigma T = 0.13$
	$\sigma V = 1.01$	$\sigma V = 0.57$	$\sigma V = 0.42$	$\sigma V = 0.14$
	RSS = 1.17	RSS = 0.72	RSS = 0.55	RSS = 0.20

Table 4. Differenced baseline error: Additional error (in cm) for differenced baselines due to UT and PM Mojave and Vandenberg used as fixed base stations

Baseline	Source of Earth Orientation			
	Astrometric	LLR	VLBI	"Super" LLR
Monument Peak - Quincy	$\sigma L = 1.13$	$\sigma L = 0.73$	$\sigma L = 0.52$	$\sigma L = 0.21$
	$\sigma T = 2.57$	$\sigma T = 1.66$	$\sigma T = 1.21$	$\sigma T = 0.48$
	$\sigma V = 2.26$	$\sigma V = 1.74$	$\sigma V = 2.02$	$\sigma V = 0.52$
	RSS = 3.61	RSS = 2.51	RSS = 2.41	RSS = 0.73
Pt. Reyes - Yuma	$\sigma L = 0.91$	$\sigma L = 0.58$	$\sigma L = 0.41$	$\sigma L = 0.17$
	$\sigma T = 2.23$	$\sigma T = 1.47$	$\sigma T = 1.06$	$\sigma T = 0.43$
	$\sigma V = 2.61$	$\sigma V = 1.46$	$\sigma V = 1.79$	$\sigma V = 0.40$
	RSS = 3.55	RSS = 2.15	RSS = 2.12	RSS = 0.61
Sta. Paula - Pearblossom	$\sigma L = 0.37$	$\sigma L = 0.24$	$\sigma L = 0.18$	$\sigma L = 0.07$
	$\sigma T = 0.69$	$\sigma T = 0.47$	$\sigma T = 0.34$	$\sigma T = 0.14$
	$\sigma V = 1.12$	$\sigma V = 0.57$	$\sigma V = 0.43$	$\sigma V = 0.14$
	RSS = 1.37	RSS = 0.77	RSS = 0.57	RSS = 0.21

Table 5. Differenced baseline error: Additional error (in cm) for differenced baselines due to UT and PM OVRO 30 used as fixed base station

Baseline	Source of Earth Orientation			
	Astrometric	LLR	VLBI	"Super" LLR
Monument Peak - Quincy	$\sigma L = 0.49$	$\sigma L = 0.27$	$\sigma L = 0.22$	$\sigma L = 0.07$
	$\sigma T = 3.81$	$\sigma T = 1.96$	$\sigma T = 1.33$	$\sigma T = 0.51$
	$\sigma V = 2.92$	$\sigma V = 1.62$	$\sigma V = 2.03$	$\sigma V = 0.46$
	RSS = 4.82	RSS = 2.56	RSS = 2.44	RSS = 0.69
Pt. Reyes - Yuma	$\sigma L = 1.23$	$\sigma L = 0.69$	$\sigma L = 0.50$	$\sigma L = 0.19$
	$\sigma T = 4.14$	$\sigma T = 2.17$	$\sigma T = 1.46$	$\sigma T = 0.56$
	$\sigma V = 4.53$	$\sigma V = 1.96$	$\sigma V = 2.14$	$\sigma V = 0.49$
	RSS = 6.26	RSS = 3.00	RSS = 2.64	RSS = 0.77
Sta. Paula - Pearblossom	$\sigma L = 2.57$	$\sigma L = 1.33$	$\sigma L = 0.91$	$\sigma L = 0.34$
	$\sigma T = 0.64$	$\sigma T = 0.34$	$\sigma T = 0.22$	$\sigma T = 0.09$
	$\sigma V = 1.58$	$\sigma V = 1.20$	$\sigma V = 1.33$	$\sigma V = 0.35$
	RSS = 3.08	RSS = 1.82	RSS = 1.62	RSS = 0.50

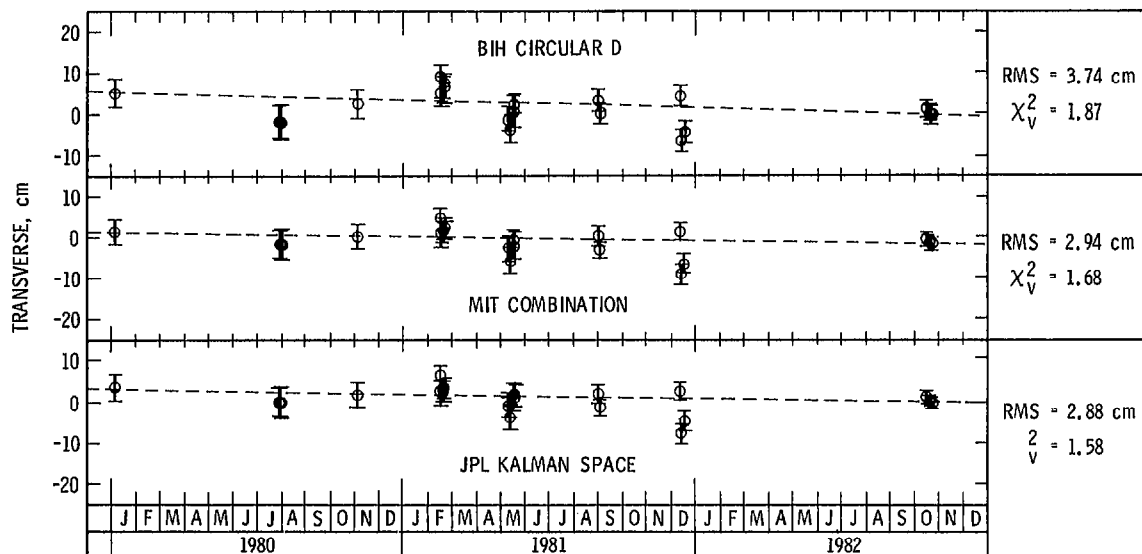


Fig. 1. OVRO 130/DSS 13 baseline, transverse component vs time

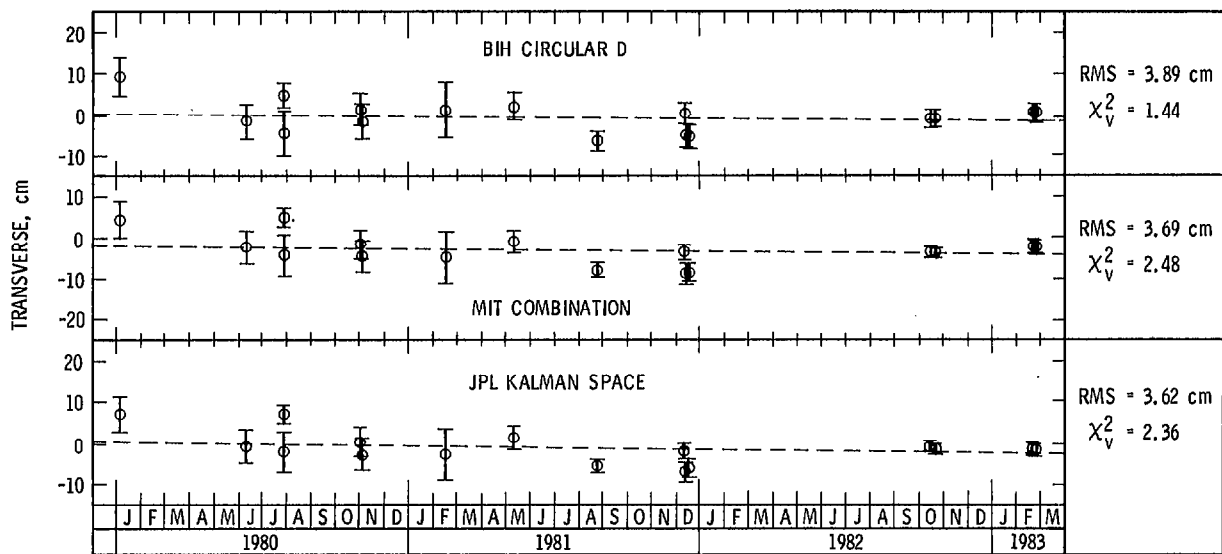


Fig. 2. OVRO 130/JPL baseline, transverse component vs time

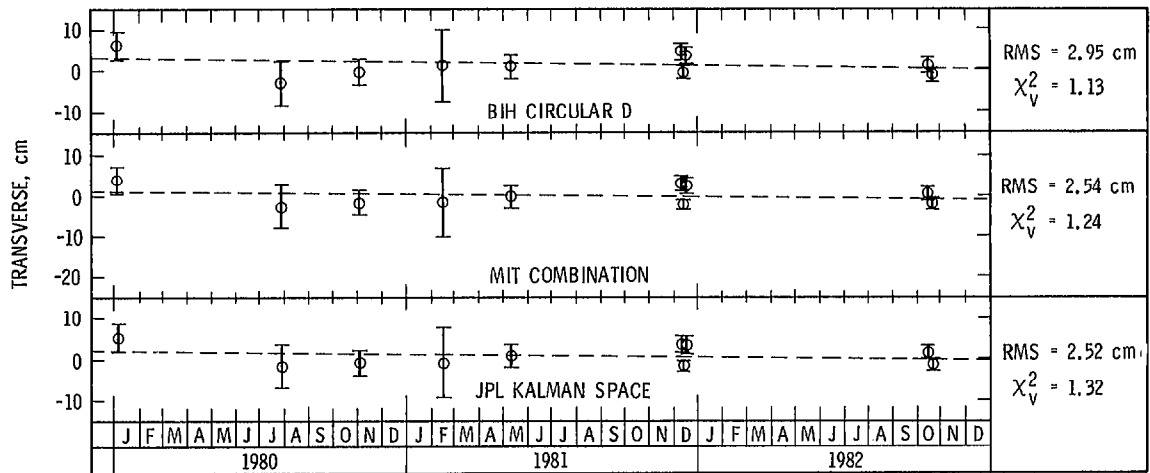


Fig. 3. DSS 13/JPL baseline, transverse component vs time

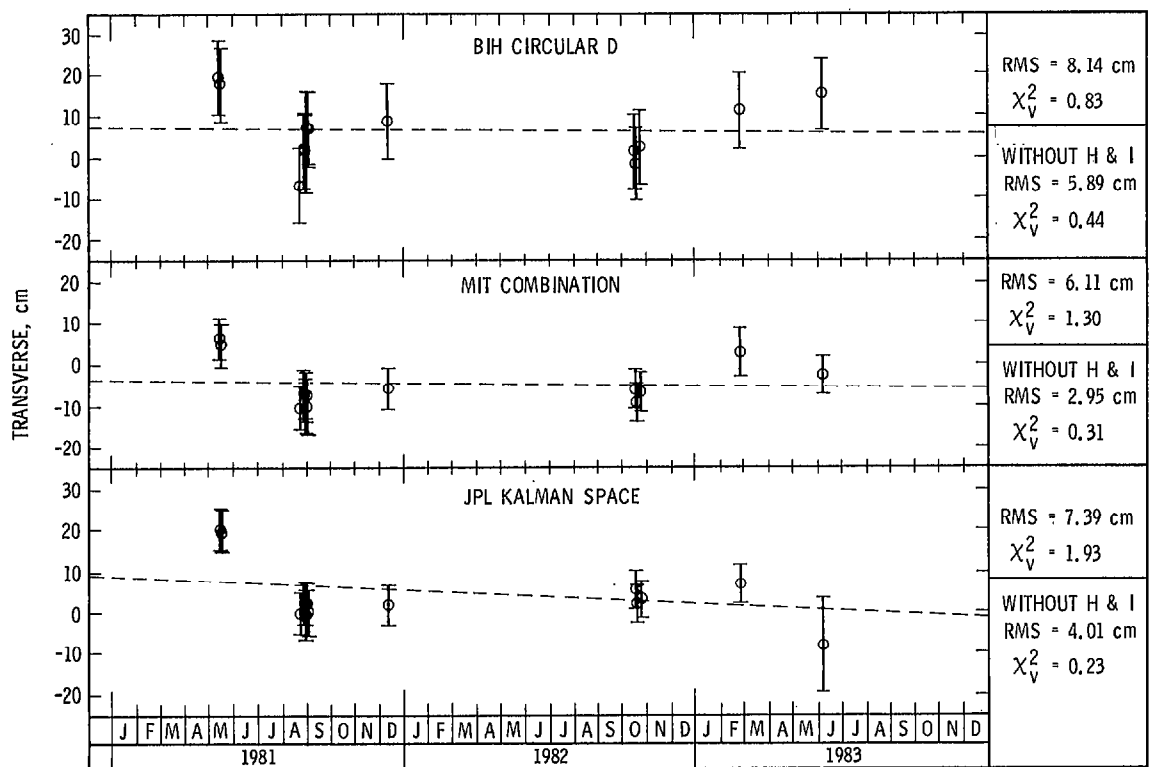


Fig. 4. OVRO 130/Ft. Davis (HRAS) baseline, transverse component vs time

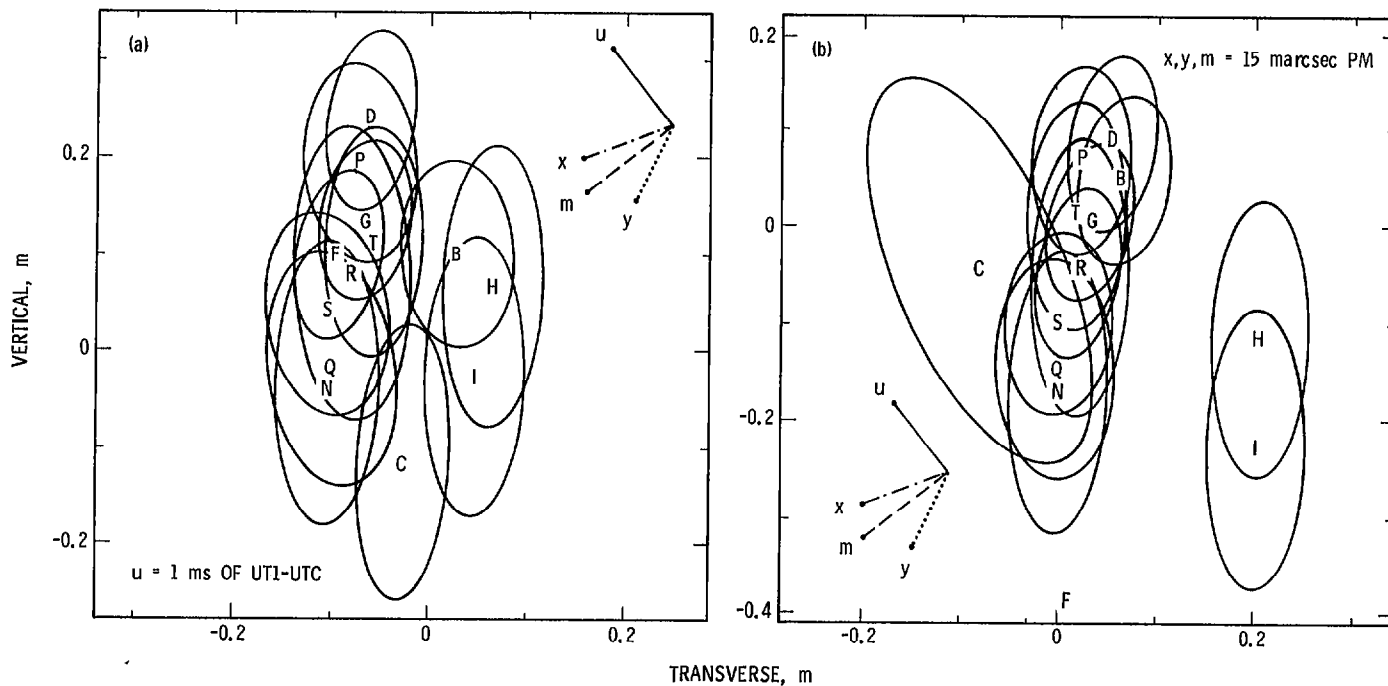


Fig. 5. OVRO 130/HRAS baseline, nonlength components. Inset vectors show directions and typical sizes of UT and PM shifts:
(a) UT1-UTC: MIT combination solution; (b) UT1-UTC: JPL-Kalman filtered space

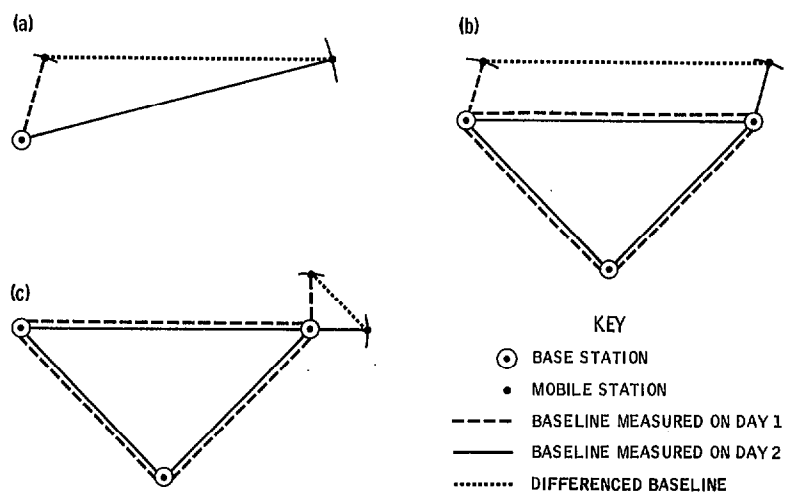


Fig. 6. Geometry of differenced baselines: (a) one base station, one mobile station; (b) three base stations, two mobile stations, long, differenced baseline; (c) three base stations, two mobile stations, short, differenced baseline

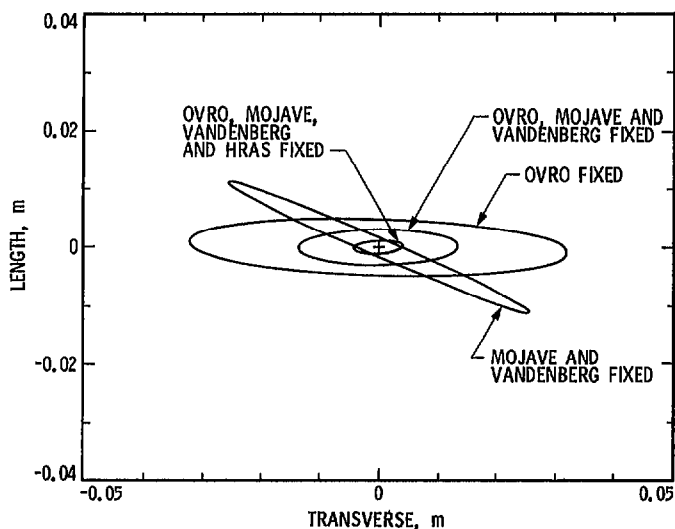


Fig. 7. Additional error from UT and PM, Monument Peak/Quincy baseline; errors with astrometric data and various base station groups

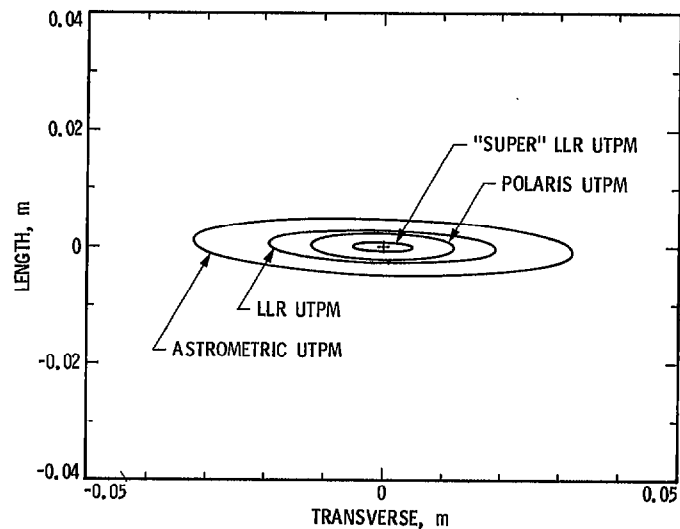


Fig. 9. Additional error from UT and PM, Monument Peak/Quincy baseline; errors with only OVRO 130 as base station and various UTPM services

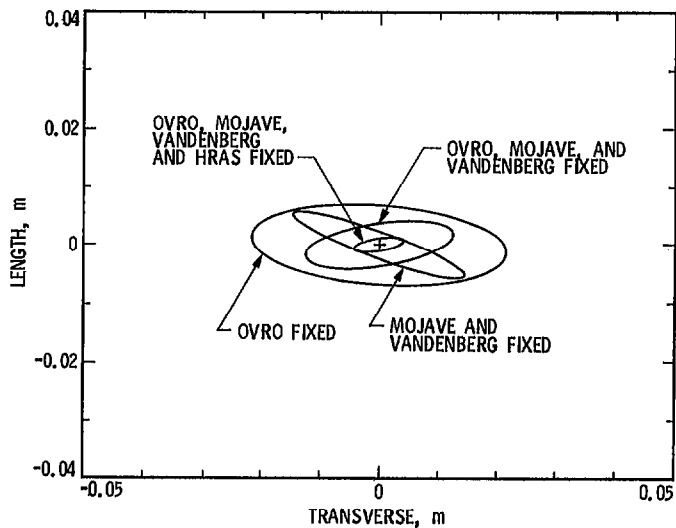


Fig. 8. Additional error from UT and PM, Pt. Reyes/Yuma baseline; errors with LLR data and various base station groups

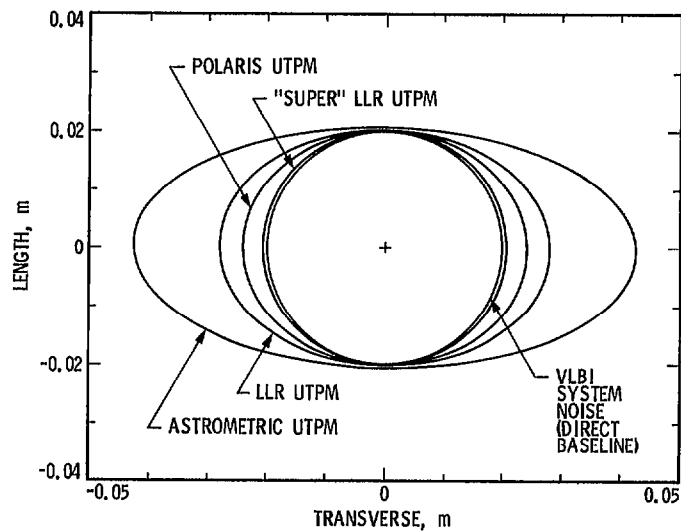


Fig. 10. Total differenced baseline error, Monument Peak/Quincy baseline; errors with only OVRO 130 as base station and various UTPM services

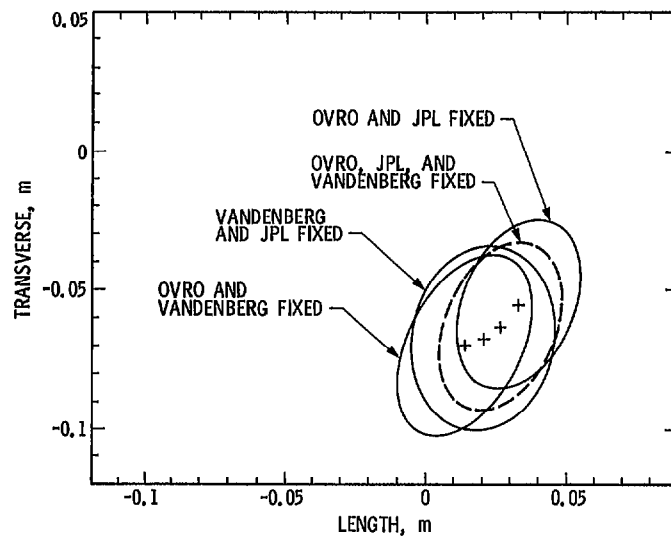


Fig. 11. Pearblossom/Pinyon baseline; MASTERFIT solutions of a differenced baseline with various pairs of base stations

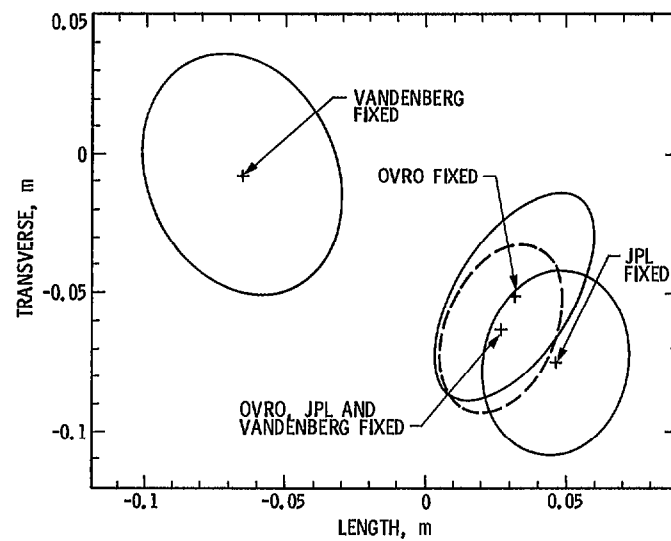


Fig. 12. Pearblossom/Pinyon Baseline; MASTERFIT solutions of a differenced baseline with various single base stations